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13. ABSTRACT *(Maximum 200 words)*

This report describes the research that has been conducted on the above referenced grant during the last nine-month period. The principal accomplishments during this time period are listed below:

- Collected typical data such as wing mass and stiffness distributions, geometric information and bending and torsional frequencies on HALE type vehicles such as Global Hawk, Darkstar, U-2, etc. and used it to develop an ordering scheme, utilizing non-dimensional parameters, for this class of vehicles.
- Developed simple structural dynamic/aeroelastic model for HALE type vehicles with isotropic wings undergoing moderate deflections in bending (normal to wing plane and chordwise), and torsion, and rigid body motion (plunge, pitch and fore and aft motion) using one mode for each elastic degree of freedom.
- Developed procedure for coupling the unsteady aerodynamic loads obtained from CFD with the structural dynamic model.
- Established fundamental scaling aeroelastic relations for testing this class of vehicles in a conventional wind tunnel.

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FINAL REPORT ON AFOSR GRANT F49620-98-1-0131

Title: Aeroelasticity and Aeroservoelasticity of Uninhabited Long-Endurance Aircraft

Period: 1/1/98-3/31/99

Amount: $60,000. -

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BACKGROUND AND OBJECTIVES

This was a limited research grant initiated for a nine-month period, starting from January 1, 1998. Subsequently a six-month, no cost extension was granted ending on 3/31/1999. The proposal that served as the basis of the grant was aimed at the development of aeroelastic and aeroservoelastic models for uninhabited long endurance aircraft (ULA). However, due to the limited period of the funding it was decided, between the Principal Investigator (Professor P. Friedmann) and the grant monitor (Major Brian Sanders), to redirect this activity towards the development of aeroelastic and aeroservoelastic scaling laws of high altitude long endurance air-vehicles (HALE). The objectives of this modified activity are provided below.

Objectives and Technical Relevance

The principal thrust of our activity was to conduct fundamental research on a new class of vehicles where geometrical and aerodynamic nonlinearities influence aeroelastic behavior. Due to the nine-month time limit it was decided to focus on the development of simple aeroelastic model for HALE type airvehicle capable of capturing the interactions between geometrically nonlinear flexible deformations and rigid body dynamics. An important part of this activity consisted of the collection of typical data for HALE type vehicles and its application to the development of ordering scheme suitable for this class of vehicles. Such ordering scheme is important for the development of reduced order models needed for aeroservoelastic studies. Another objective was the development of a procedure for coupling the structural dynamic model with the unsteady aerodynamic loads obtained from computational aerodynamics. The aeroelastic model will be used in combination with our two-pronged approach, to develop aeroelastic-scaling laws for this class of vehicles.

AEROELASTIC MODEL FOR A GENERIC HALE TYPE VEHICLE

HALE Vehicles Fundamental Characteristics

This class of vehicles has large aspect ratio flexible wings, which can be described by geometrically nonlinear, moderate deflection beam theory. The vehicles have a small fuselage (relative to conventional aircraft), and perform mild maneuvers. A typical vehicle in this category is shown in Fig. 1. These vehicles fly at high altitude (40,000-100,000 ft.) and operate at low Reynolds numbers (order of magnitude less than conventional aircraft). The unsteady aerodynamic environment of airfoils operating in this low Reynolds number range is characterized by flow with intermittent separation. There is a strong potential for interaction between flexible aircraft modes and rigid body vehicle modes, in these vehicles. The uninhabited nature of these vehicles implies high authority control systems, which can interact with vehicle flexibility. Additional control systems capable of modifying aero-structural interactions will also be present on this class of vehicles providing an opportunity for constructive uses of vehicle flexibility (or aeroelasticity) to enhance vehicle performance.

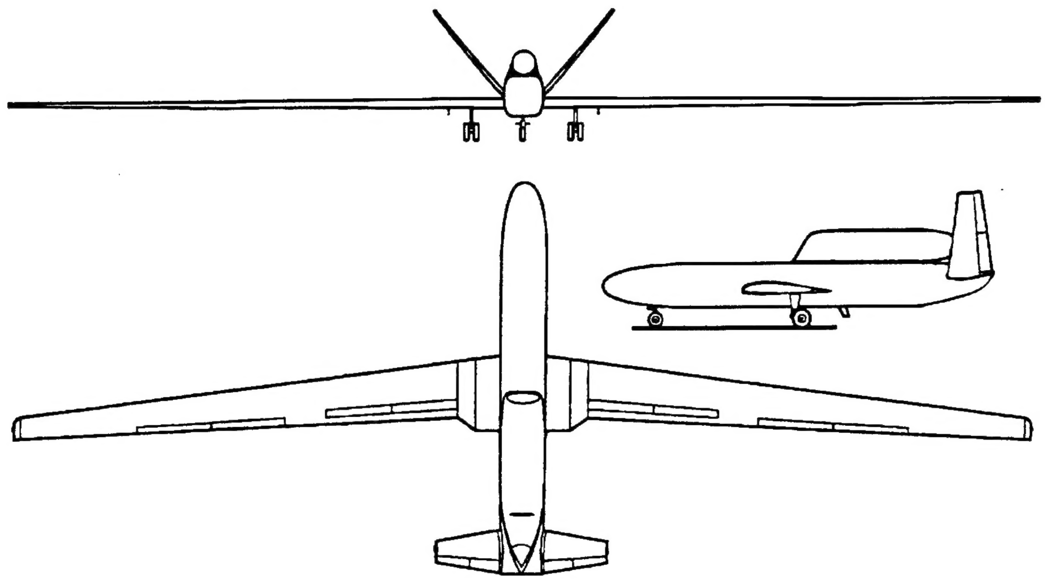

Figure 1. Typical HALE Vehicle (Similar to Global Hawk).

Basic Kinematic and Structural Assumptions

Wings undergo moderate deflections, which imply small strains and moderate deflections. Wings built of composite materials, represented by anisotropic structural model, transverse shear and out of plane warping are included. Wings have moderate amounts of pre-twist and coupled chord-wise bending, out of plane of the wing bending, twist and axial deformation. A one dimensional, geometrically nonlinear beam theory is used to describe the span-wise structural dynamic behavior, and a separate linear two dimensional cross sectional analysis is used to generate the composite structural cross sectional constants

Structural Dynamic Model

Based on these assumptions we have developed a finite element model for high aspect ratio composite wings undergoing moderate deflections. This model includes, shear, warping, and composite construction (material anisotropy). It is suitable for the modeling of wings having arbitrary multicell cross-sections. This finite element model consists ot a 23 degree of freedom geometrically nonlinear beam type finite element that describes the spanwise properties of the wing, shown in Fig. 2. This is combined with a separate two dimensional finite element model consisting of quadrilateral element, that computes the

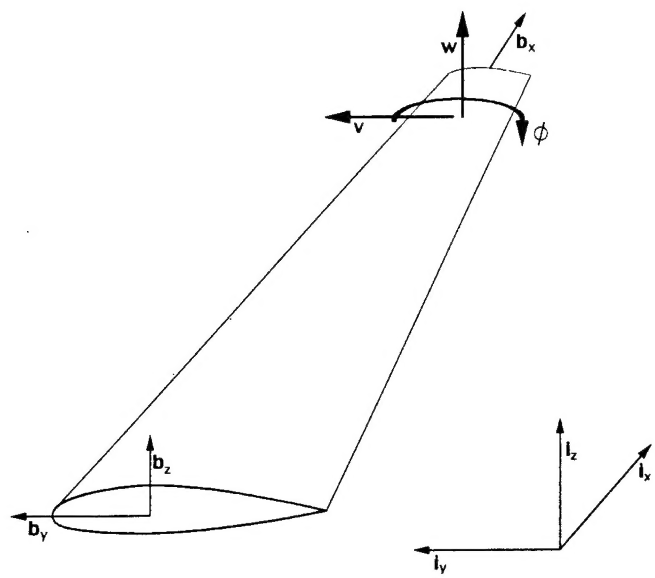

Figure 2. Typical large aspect ratio HALE wing.

cross-sectional constants of the composite multicell wing section. This analysis is described in detail in Ref. 1.

Aeroelastic Model

The aeroelastic model is obtained by coupling this structural dynamic model with CFD based loads which are obtained from the unsteady solution of the Navier Stokes equations for a two dimensional airfoil. These loads are applied on the large aspect ration wing in a modified strip theory manner.

ACCOMPLISHMENTS

The principal accomplishments during this time period are listed below:

- Collected typical data such as wing mass and stiffness distributions, geometric information and bending and torsional frequencies on HALE type vehicles such as Global Hawk, Darkstar, U-2, etc. and used it to develop an ordering scheme, utilizing non-dimensional parameters, for this class of vehicles.
- Developed simple structural dynamic/aeroelastic model for HALE type vehicles with isotropic wings undergoing moderate deflections in bending (normal to wing plane and chordwise), and torsion, and rigid body motion (plunge, pitch and fore and aft motion) using one mode for each elastic degree of freedom.
- Developed procedure for coupling the unsteady aerodynamic loads obtained from CFD with the structural dynamic model.

- Established fundamental aeroelastic scaling laws for testing of this class of vehicles, which operate at very low Reynolds numbers and high altitudes, in a conventional wind tunnel. Part of this material is included in a recent paper that will be published in October 2000 [Ref. 2].

REFERENCES

1. Yuan, K. A., and Friedmann, P. P., "Aeroelasticity and Structural Optimization of Composite Helicopter Rotor Blades with Swept Tips," NASA CR 4665, 1995.
2. Friedmann, P. P. and Presente, E., "Active Control of Flutter in Subsonic Flow and Its Aeroelastic Scaling," to be published in the Journal of Guidance Control and Dynamics, Vol. 23, No. 5, September-October 2000.